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DEWATERING COFFERDAM FOR THE TRIDENT SUBMARINE DRYDOCK.(U)
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TECHNICAL NOTE

TN NO: N-1636

TITLE: DEWATERING COFFERDAM FOR THE TRIDENT SUBMARINE DRYDOCK

AUTHOR: J. B. Forrest

DATE: June 1982

SPONSOR: Naval Facilities Engineering Command

PROGRAM NO: YF60.534.091.01.603

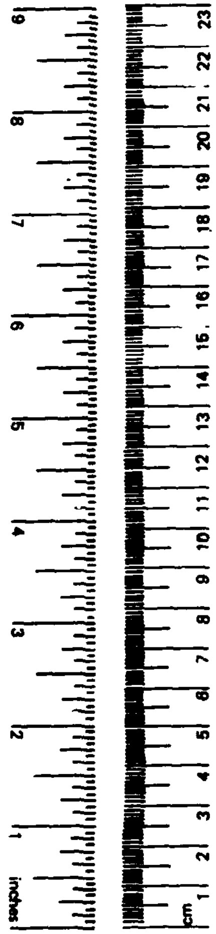
NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CALIFORNIA 93043

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

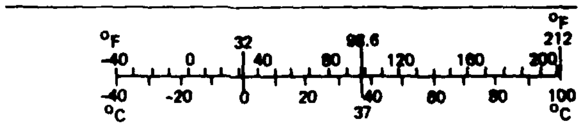
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	i ches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The dewatering cofferdam for the TRIDENT nuclear submarine drydock at Bangor, Washington, presented many challenges. These included water depths up to 25 meters, artesian pressures 10 to 13 meters above mean sea level, difficult pile driving conditions, and the potential for seismically induced liquefaction of the fill in the cofferdam cells. Design ground motions of 0.15 g dictated that fill densities exceed 75% density index.

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20. Continued

Deep compaction was achieved using a large vibratory probe. Inclinometer, strain gage, and optical survey measurements on the sheet piles and extensive piezometric data was obtained. Significant observations were that (1) deep cell compaction can markedly increase fill density without increasing lateral cell pressures unduly, and (2) maximum interlock tension may be well below the one-quarter height of exposed sheeting as often assumed in design.

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TN-1636 20 pp illus June 1982 Unclassified

1. Cofferdams 2. Dewatering I. YF60.534.091.01.603

The dewatering cofferdam for the TRIDENT nuclear submarine drydock at Bangor, Washington, presented many challenges. These included water depths up to 25 meters, artesian pressures 10 to 13 meters above mean sea level, difficult pile driving conditions, and the potential for seismically induced liquefaction of the fill in the cofferdam cells. Design ground motions of 0.15 g dictated that fill densities exceed 75% density index. Deep compaction was achieved using a large vibratory probe. Inclinometer, strain gage, and optical survey measurements on sheet piles and extensive piezometric data were obtained. Significant observations were that (1) deep cell compaction can markedly increase fill density without increasing lateral cell pressures unduly, and (2) maximum interlock tension may be well below the one-quarter height of exposed sheeting as often assumed in design.

CONTENTS

INTRODUCTION

On several occasions during construction of the drydock for Trident Nuclear submarines at Bangor, Washington, the Naval Civil Engineering Laboratory was tasked by the Officer in Charge of Construction (OICC), TRIDENT to provide technical consultation services. These services included estimating the overall stability of the cofferdam during unwatering and evaluation of cofferdam resistance to seismic liquefaction. As an outgrowth of these services, the Naval Civil Engineering Laboratory (NCEL), Port Hueneme, Calif., accepted custody of much of the construction data following disestablishment of OICC, TRIDENT. This report presents a very brief overview of the initial construction history of this structure.

The planning and construction of this drydock presented many challenging and unusual geotechnical problems. The treatment of these problems plus a sampling of some of the very valuable soil response data obtained are presented herein.

The TRIDENT nuclear submarine drydock is located at the TRIDENT support base on the Hood Canal at Bangor, Wash. (Figure 1). Construction was carried out in two main phases. The first phase, including site preparation, construction of the dewatering cofferdam, and site dewatering, is the subject of this report.

Drydock designers were Fay, Spofford, and Thorndike Inc. of Boston, Mass., with Haley and Aldrich, Inc. of Cambridge, Mass., as the geotechnical consultants. The contractor for this phase was Willamette-General-Manson, A Joint Venture, of Portland, Ore.

SPECIAL FEATURES

The TRIDENT drydock, unlike typical graving drydocks, is located entirely offshore. In order not to interfere with salmon fingerling migrations, it was constructed approximately 210 meters beyond the shoreline in a triangular-shaped waterfront structure known as the Delta (Figure 2).

The Delta is a three-sided waterfront facility, two sides of which are refit piers; the third side, which is parallel to shore, contains the drydock. The drydock site is directly over the terminus of an artesian aquifer in which the natural pressure head directly under the drydock site was over 10 meters above mean lower low water (MLLW). This artesian pressure, plus the environmental impact aspects of the site and facility economics, dictated the selection of a gravity-type drydock to be built in the dry. To construct a drydock in the dry necessitated the design and construction of a cofferdam structure to encircle the drydock site, thereby allowing dewatering. The depths of water at this site

necessitated the use of high-strength steel sheet piles in the construction of the circular-cell cofferdam. A typical design cross section of the site is shown in Figure 3. Because of the length of sheet piles required, one of the only two U.S. manufacturers of high-strength sheet piles informed the Navy during the bid period that they were not going to bid the project as a supplier. They cited numerous reasons, including inability to assure quality control in rolling of the long sheets. Other problems encountered were hard material such as cobbles interfering with dredging, difficulty of driving sheet piling into the till, and the necessity for deep compaction of the cell fill materials because of the seismic liquefaction hazard.

SITE DESCRIPTION

The geotechnical investigation included drilling and sampling; measurement of piezometer heads, artesian flows, and permeability; conducting pumping tests; and carrying out geophysical surveys. Fifty-seven test borings were drilled between November 1974 and May 1975 — 40 over water, 17 on land.

Soil Profile

The major soil strata at the drydock site are a relatively thin, recent alluvium, underlain by a moderately thick till layer which, in turn, is underlain by a deep sand and gravel aquifer. The recent alluvium stratum consists of very loose to medium dense sands and gravels containing traces of shell fragments and silt.

The till stratum consists of medium dense to very dense, silty coarse to fine sand and coarse to fine sandy silt containing traces of gravel and clay. This soil is heavily precompressed, exhibits high strength and low compressibility, and has relatively low permeability.

The sand and gravel aquifer consists of interbedded, medium compact to very compact sands and gravels, with occasional lenses and layers of silt with traces of organic material and shell fragments. The sands and gravels are heavily precompressed, exhibit high internal friction and low compressibility, and have moderate permeability.

The directional artesian aquifer vents to the Hood Canal seaward of the site.

Artesian Heads

Piezometric heads in the aquifer ranged from approximately 9 to 12 meters elevation above MLLW. Preliminary pumping tests indicated that, with a moderate pumping rate from a single well on shore, it was possible to achieve significant pressure relief in the aquifer throughout the refit Delta area. The test data disclosed that, from the standpoint of flow, the aquifer exhibits an overall average permeability corresponding to that of very fine sand. The test well pumping confirmed that it would be technically feasible to significantly reduce the artesian pressure at the drydock site.

The geophysical measurements indicated relatively high seismic velocities, which reflect the dense nature of the in-situ soils.

Because of the high artesian pressures in the aquifer under the drydock site, it was not feasible to dredge the bottom materials until after the artesian pressure had been reduced by an amount approximating the submerged weight of the material to be removed. If dredging had been undertaken without properly reducing the artesian pressure, it is likely that large upward gradients and boils would have developed within the bottom of the dredge area. Such an occurrence would have made the site unusable for drydock construction because it would have loosened the in-situ underlying soils and made them unsuitable to support the drydock.

Since it was not feasible to provide a drydock having sufficient weight to offset the total combined weight of the excavated soils and the water displaced by the drydock, the artesian pressures had to be permanently maintained at a reduced level.

SEISMIC ANALYSIS

The drydock is located in an area of moderate seismic activity. Based upon a seismic risk analysis,* there is a 30% possibility of experiencing an effective peak ground surface acceleration of 0.15g. The average return period of this acceleration is roughly 133 years. This acceleration level is expected to result from earthquakes having focal depths of less than 25 km; however, recent experience in the Puget Sound area has been that of deeper earthquake sources. The 0.15g level with an amplification factor of 1.33 was assumed for design of the cofferdam.

COFFERDAM CONSTRUCTION

Construction procedures included the following:

1. Installation of deep wells to reduce artesian aquifer pressures to approximately MLLW elevation.
2. Dredging of any soft materials existing at the site. Because steel sheet piling could not significantly penetrate the dense till, some of this material had to be removed in places.
3. Placement of templates, construction of the cellular cofferdam, and placement of granular fill to 5 meters elevation MLLW.
4. Densification of the fill using a vibratory probe.

*Naval Facilities Engineering Command. Contract Report: Drydock, Trident support site, Bangor, WA. Preliminary engineering study, vol II (part B): Site investigation, by Haley and Aldrich, Inc. Boston, Mass., Fay, Spofford and Thorndike Inc., Oct 1975. (Contract N68248-73-C-0004)

5. Backfilling of cut areas adjacent to the cofferdam and building of an outside semi-impervious berm to reduce seepage.

6. Construction of wells and placement of pumps through the cell fills into the aquifer and inside the cells and arcs (refer to Figure 2).

7. Dewatering of cofferdam while pumping as required from deep and shallow wells (water levels in cells to be maintained not more than 5 feet above the water level behind the cofferdam, and piezometric heads in the deep aquifer never to exceed cofferdam water levels).

Prior to the start of dredging, six 30-cm-diam deep wells were constructed onshore into the aquifer. During the dredging and the construction of the steel pile cofferdam, the wells were pumped to maintain the artesian head at the drydock at MLLW. The pumps individually discharged into the Hood Canal. The pumps remained in operation until the wells at the drydock became operational.

Twelve 30-cm-diam deep wells were installed through the cell fill into the aquifer. During construction of the drydock floor, the wells were pumped to maintain the artesian head at the drydock at -22 meters.

The 11 wells in the permanent cells were to be converted to gravity wells to maintain the artesian pressure at the drydock between 4 and 5 meters elevation. The total maximum flow rate was less than the expected 1,200 gpm.

Pile Driving

Because of the water depths at the site, overturning considerations required cofferdam cell diameters of about 23 meters. The large bursting stresses generated by cells of these dimensions necessitated use of high-strength steel sheet piles. Sheet pile material conformed to ASTM A572 Grade 50, with a minimum yield strength of 345,000 kPa. U.S. Steel PSx32 sheet piles were used with 40-degree, 555 N/lin. m (38 lb/lin. ft) extruded y-sections for the cell-arc connections.

The sheet piles have an 11.51-mm web thickness and weigh 657 N/m (45 lb/lin. ft). Minimum interlock strength is specified as 408,650 N/m.* Pile tips were generally driven to a resistance of 4 blows/cm (10 blows/in.) using a McKierran-Terry Model 1083 double-acting steam hammer with a rated energy of 17,800 joules (13,150 ft-lb) at 105 blows/min. Typical sheet pile penetration for cell 8 is shown in Figure 4 where the radial scale shows depth of embedment of the pile tips into the till. Individual pile overall lengths are represented for randomly selected piles. For example, at an azimuth of 40 degrees, a 67-ft-long sheet pile has been driven to an embedment of approximately 5 feet.

Cell Compaction

Because of the potential for earthquake-induced soil liquefaction within the cofferdam cells and arcs, compaction of the graded granular fill was carried out following placement.

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*United States Steel. Steel sheet piling handbook. Pittsburgh, Pa., Apr 1976.

Fill material was placed beneath the water surface in the cofferdam cells and arcs by a clamshell and then compacted by means of a vibratory probe. Probing patterns and procedures were developed by experiment to insure that the final in-situ fill relative densities were in excess of 75%.

The experimental probe placement patterns used for cell 8 are shown in Figure 5. Probe location was controlled by survey techniques, but verticality of the probe was monitored by visual inspection. The probe measured 51 cm in diameter and 30 meters long. It generated 120 kg-cm horizontal thrust with a centrifugal force of 4 metric tons and a variable 15,000 to 25,000 kg-cm vertically with a centrifugal force of 65 to 100 metric tons.

The compaction procedure was as follows:

1. Probe positioned and inserted using a crane (probe was equipped with water-jetting capability to aid insertion where required).

2. Fill probed to just above dredge depth, making sure no jetting was conducted near the till foundation, and vibrated approximately 5 minutes.

3. Compaction procedure consisted of raising the probe 1.8 meters and vibrating for approximately 20 seconds and lowering it 0.9 meter for an additional 20 seconds. Cycle was repeated until the probe had been raised 6.4 meters, then permitted to repenetrate until it met resistance. Then the 1.8-m/0.9-m cycle was repeated until the probe had been extracted a total of 13 meters above the dredged bottom, and the repenetration to refusal (without jetting) was repeated. This cycle was then repeated at the top of the fill until the probe reached the top the second time using the 1.8-m/0.9-m increments.

In order to avoid damage to the sheet piles, the probe was permitted to approach no closer than 3 meters from them.

Probing was conducted in both cells and connecting arc fills.

Measurements

The cofferdam structure had to be instrumented and monitored closely throughout the construction period. Inclinometer casings were affixed to several sheet piles, and vibrating wire strain gauges were installed at numerous elevations. To monitor stress, IRAD Model SM-5B vibrating wire strain gages were installed on several cells at various elevations between the dredge line and mean tide level. The strain gages were installed on sheets 8-1 and 8-2 in cell 8, and on sheets 5-1 through 5-5 in cell 5, as shown in Figure 6. Strain gages were mounted on the inside and outside of the sheet pile at each instrumented position. Up to four instrument levels (A, B, C, and D) were provided at each sheet. At some levels, two sets of two gages each (four gages) were installed at the level; at other sheets, only one set of two gages was installed. A summary of the installed gages can be found in Figure 6.

In addition, extensive piezometer readings were taken, both during compaction of the cofferdam cells and during cofferdam dewatering and pumping tests. Other monitors included optical survey instruments and diver inspections.

MEASURED DATA

Fill Materials

Only typical results from the extensive data acquired are presented herein. These include soil compaction and piezometer data and inclinometer and strain gage results. Figure 7 shows a typical grain size distribution from a sample taken from arc 2-3 (Figure 2). Results of consolidated undrained triaxial compression tests, performed on two samples of this fill and compacted to a relative density of 75%, are shown in Figure 8.

Density determinations (shown in Figure 9) following probe compactions in cell 8 are based upon standard penetration test correlations with relative density.* The estimated unit weights of the cell fill material at instrumented cells 5 and 8 are summarized in Table 1. Unit weights were calculated for conditions before and after probe compaction of the cells and are based on the following:

- Laboratory determinations of maximum and minimum dry unit weights of fill material sampled from the instrumented cells
- Average relative density determined in test borings made in each cell before and after compaction.

Piezometric data recorded during probe penetrations are not reported herein; nevertheless, very large pore pressures were generated in the vicinity of the probe. The soil fill material near the probe tip liquefied during compaction and high pore pressure gradients existed in the immediate vicinity of the probe.

Optical Surveys and Inclinometer Data

Data presented herein deal primarily with deformations occurring during the dewatering phase of the drydock. Figures 10 and 11 represent horizontal and vertical movements, respectively, of some of the cells during the dewatering phase, as monitored by optical survey techniques.

Inclinometer casings were installed along the inner faces of several steel piles and protected by enclosing angles that were welded over them. Figure 12 shows inclinometer results during this period for cell 5.**

*H. J. Gibbs and W. G. Holtz. "Research on determining the density of sand by spoon penetrometer test," in Proceedings of the Fourth International Conference on Soil Mechanics and Foundation Engineering, London, England, 1957, vol I.

**Considerably more inclinometer and survey data were generated during this project, but only a few representative measurements are reported herein.

Lateral Stresses

The size of this cofferdam, together with the required compactive efforts, presented the potential for unusually high bursting stresses in the cofferdam cells. Profiles of sheet pile interlock tension based on the strain gage measurements for cells are shown in Figure 13. These results are representative of stabilized soil conditions when interlock tensions were near maximum.

Data shown are for measurements from sheet piles on the main inboard and outboard exposed arcs of the cells (main sheets) as well as the instrumented sheet piles on the common walls located two sheet piles in from the y-connections. The upper and lower limit curves correspond to data from the main sheet piles.

The interlock tension near the dredge lines as estimated between measurement points is shown by dashed lines in Figure 13. Values of the coefficient of lateral soil pressure, k_H, were backfigured from the profiles of interlock tension using the cell fill unit weight data shown in Table 1.

CONCLUSIONS

Values of the coefficient of lateral soil pressure, k_H backfigured from profiles of interlock tension, are shown in Table 2. Calculations were made for the upper and lower limit profiles of interlock tension for conditions both before and after compaction. Interpretation of the strain gage data indicates that the point of maximum interlock tension may be lower than the H/4 point (one-quarter of the cofferdam height above the dredge line) that is often assumed in design. Insufficient data exist to make a precise determination, but it appears that the point of maximum interlock tension is located about 10 feet above the dredge bottom. Although deep cell compaction markedly increased fill density, it did not produce final average lateral soil pressure values as high as 50% of the vertical stress.

Table 1. Estimated Fill Unit Weights at Instrumented Cells

Cell	Fill Condition	Before Compaction Full Depth		After Compaction 0 - 10.5 m		After Compaction 10.5 - 20 m	
		I_D (%)	γ (kN/m^3)	I_D (%)	γ (kN/m^3)	I_D (%)	γ (kN/m^3)
5	Saturated	50	21.0	80	22.3	70	21.8
	Moist	50	19.9	80	21.5	70	21.1
	Buoyant	50	10.9	80	12.2	70	11.9
8	Saturated	50	20.7	88	21.6	76	21.3
	Moist	50	19.6	88	20.8	76	20.4
	Buoyant	50	10.6	88	11.6	76	11.3

Table 2. Estimated Coefficient of Lateral Soil Pressure at Instrumented Cells

Cell	Elevation (m)	Coefficient of Lateral Pressure, k_H: Before Cell Compaction		After Cell Compaction	
		Lower Limit	Upper Limit	Lower Limit	Upper Limit
5	0	0.18	0.50	0.16	0.39
	-6	0.26	0.45	0.31	0.44
	-12	0.29	0.42	0.37	0.47
8	0	0.23	0.28	0.13	0.33
	-6	0.22	0.28	0.22	0.39
	-12	0.23	0.28	0.26	0.42

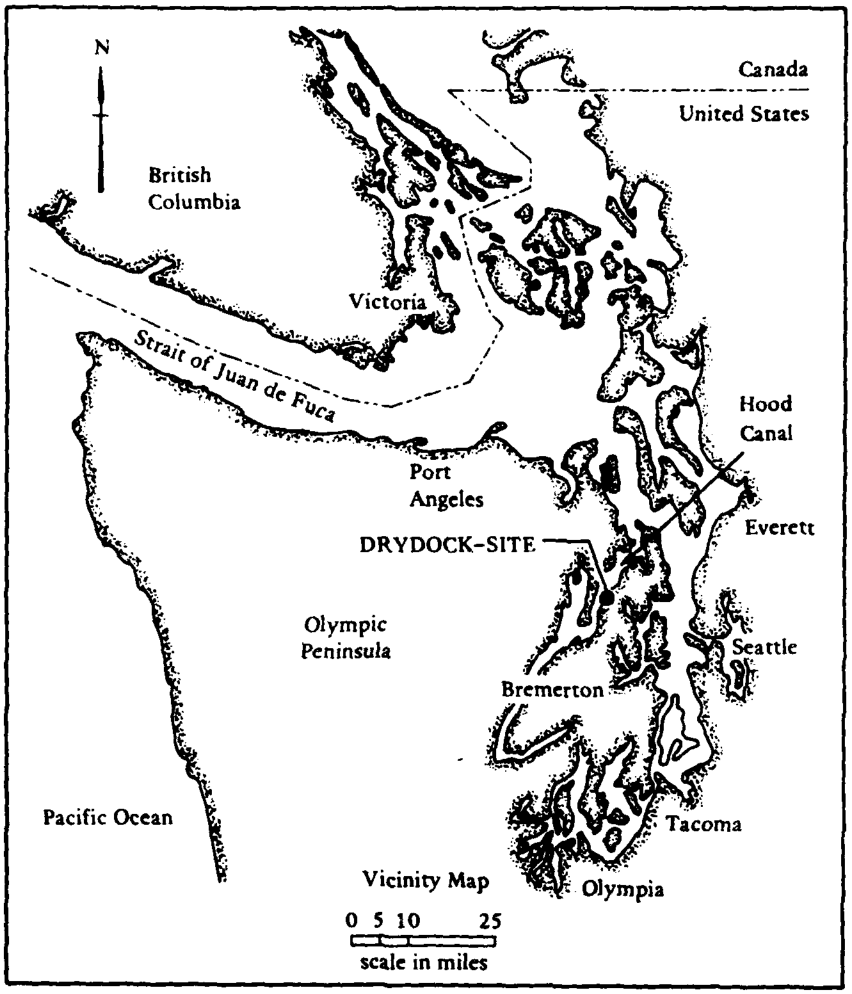


Figure 1. Regional location of site.

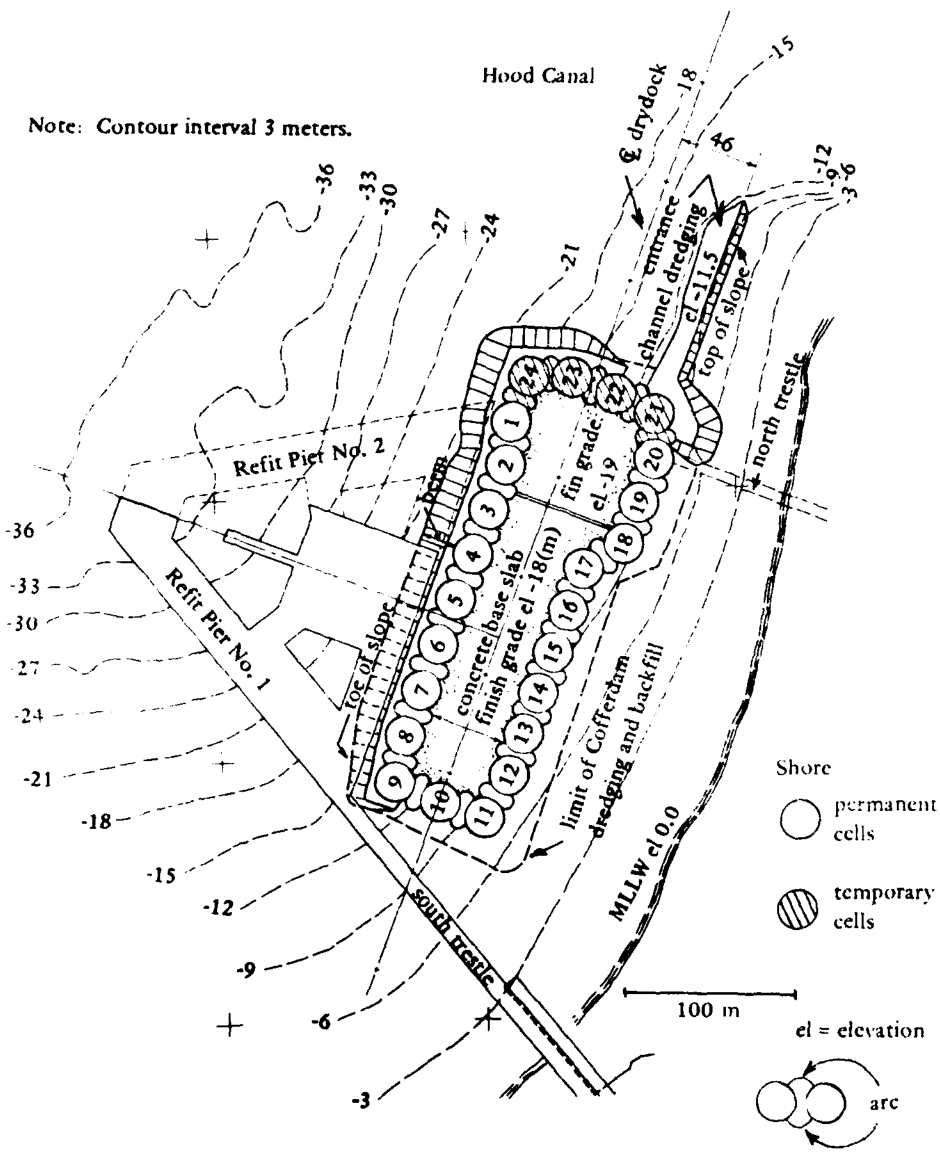


Figure 2. Delta site plan in Hood Canal.

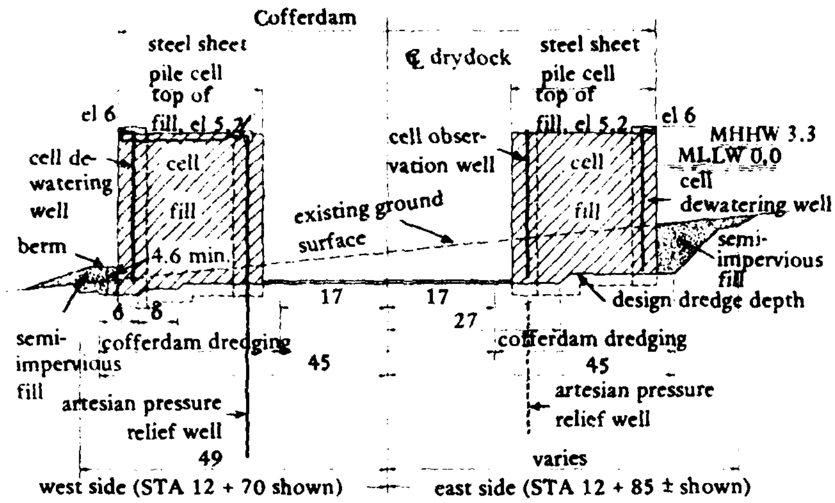


Figure 3. Typical cross-section through cofferdam (dimensions in meters).

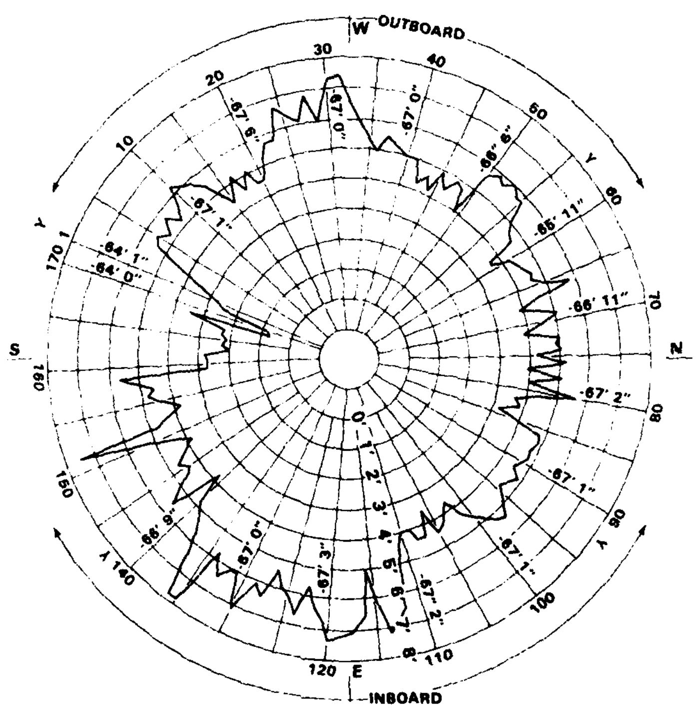


Figure 4. Pile tip penetration for Cell 8.

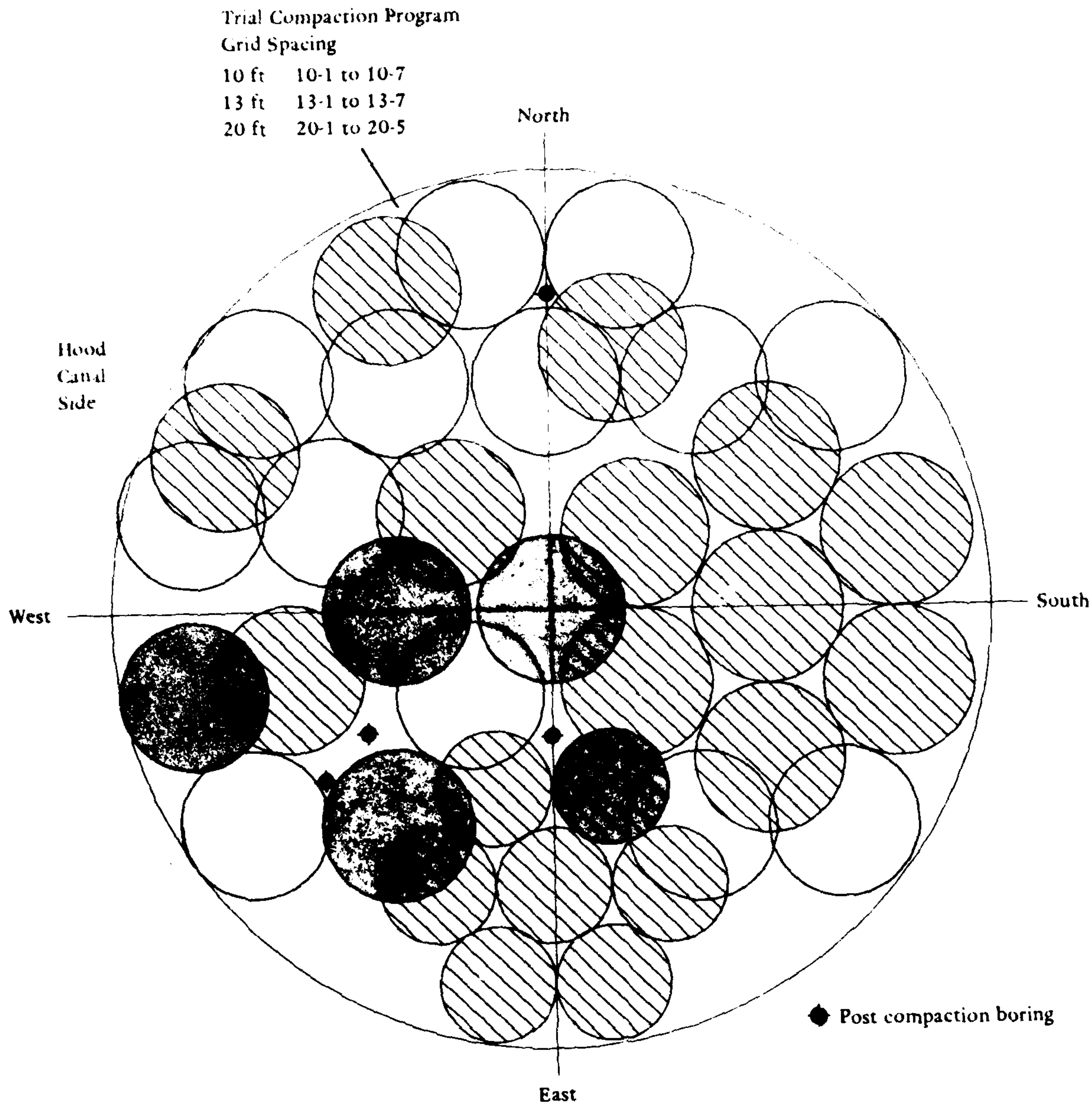
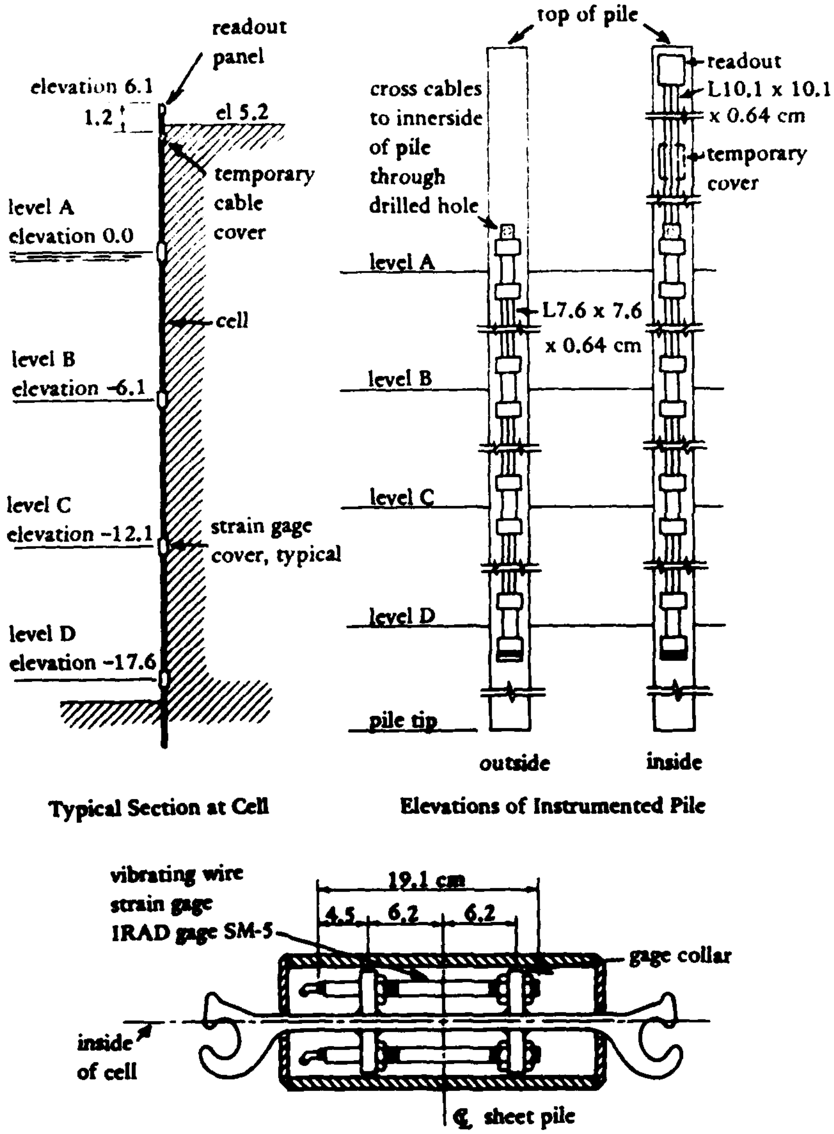


Figure 5. Vibratory probe patterns for Cell 8.



Detail Section - Strain Gage Installation

Gage Installation Summary

Sheet Pile	Level A	Level B	Level C	Level D
8-1	2	4	4	4
8-2	2	2	4	2
5-1	4	4	4*	4
5-2	4	4	4	4
5-3	4	4	4	4
5-4	-	4	4	4
5-5	4	4	4*	4

Figure 6. Strain gage installation.

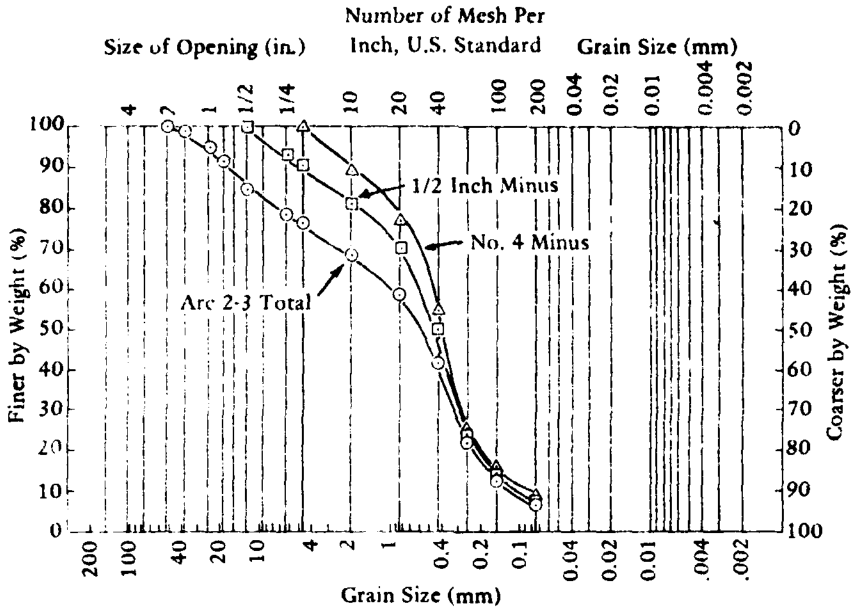


Figure 7. Fill gradation from Arc 2-3.

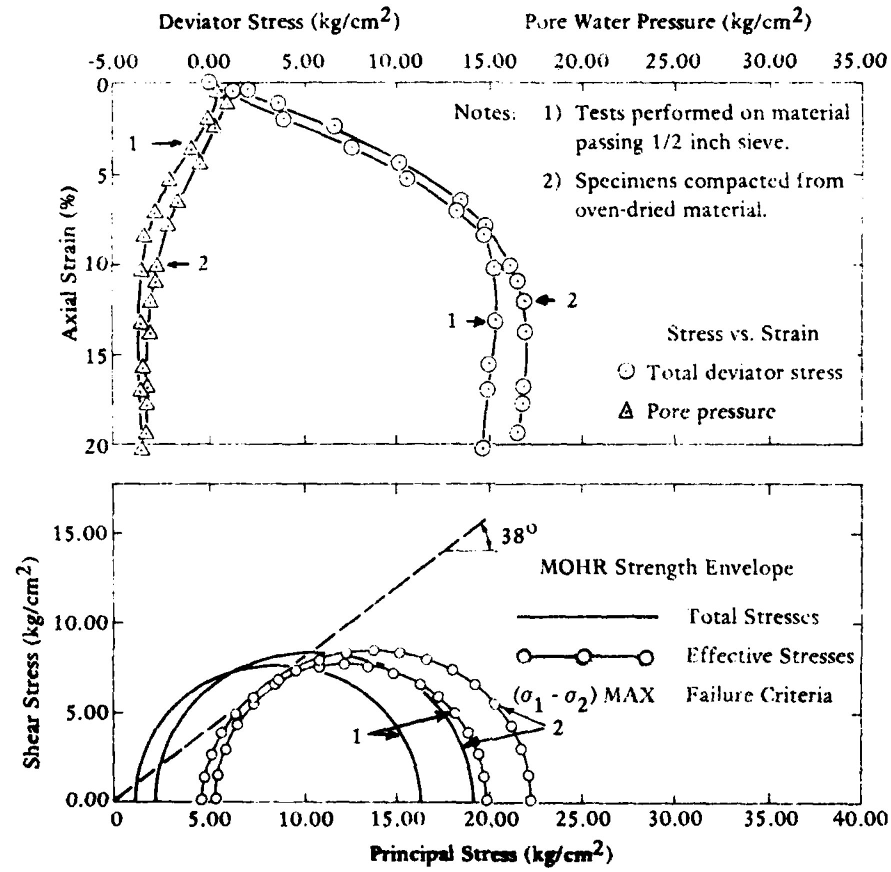


Figure 8. Consolidated, undrained, triaxial compression test results for ARC 2-3 fill.

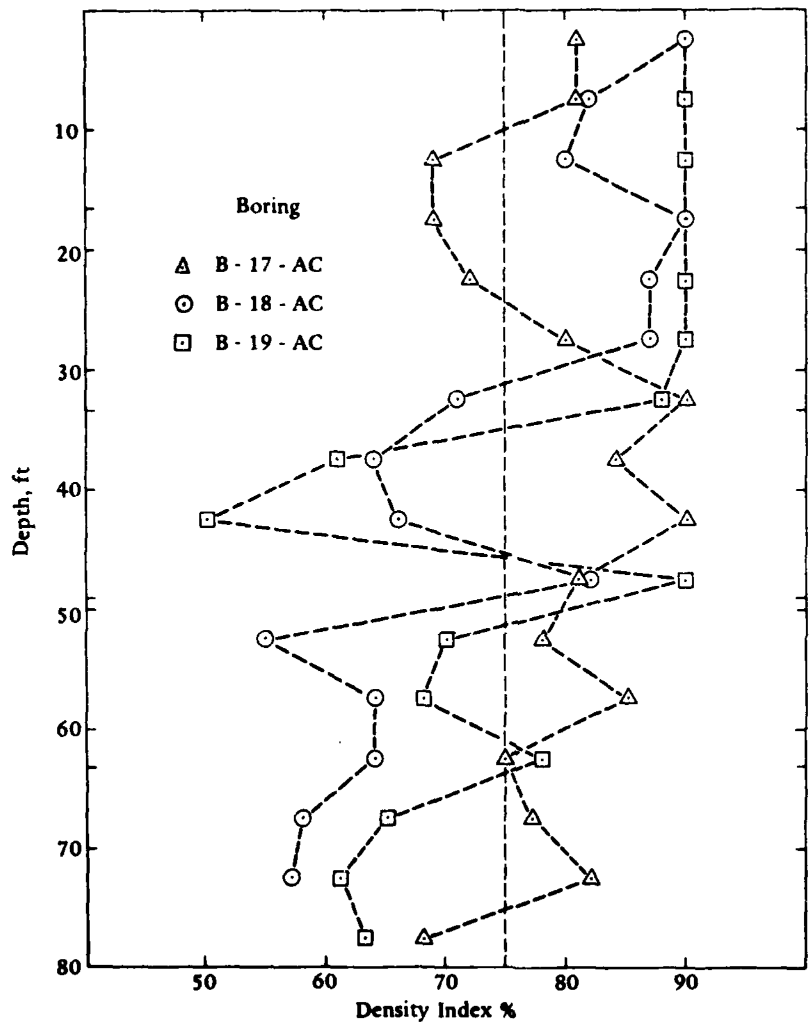


Figure 9. Density index following probe compaction of Cell 8. Inirial density index was less than 50%.

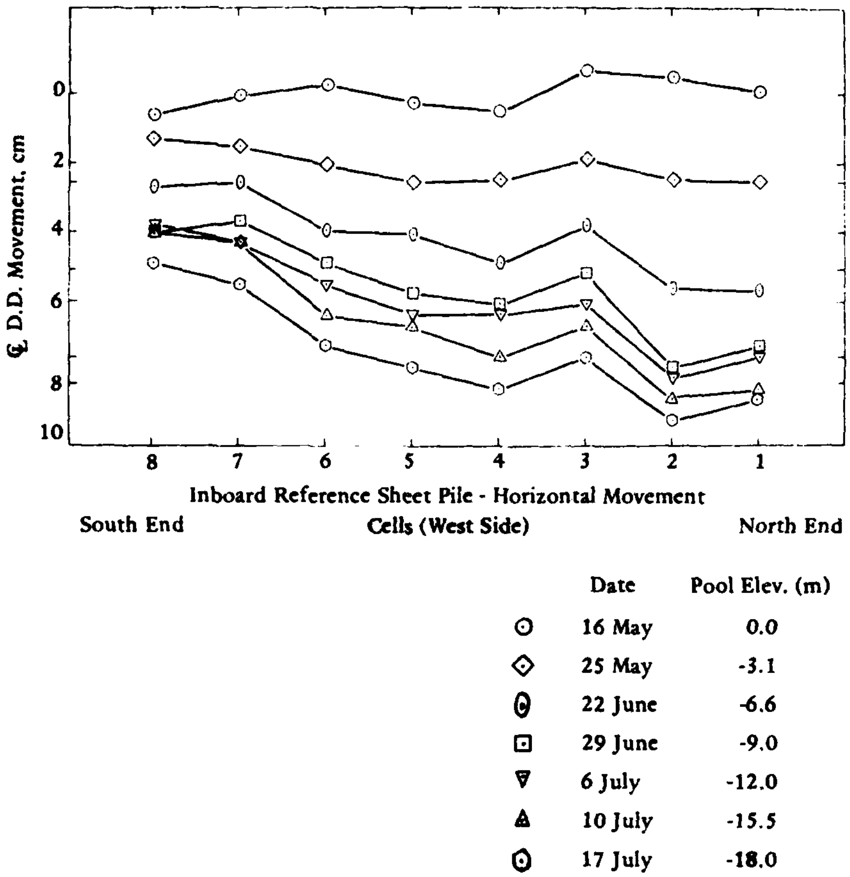


Figure 10. Horizontal cell movements during dewatering of cofferdam.

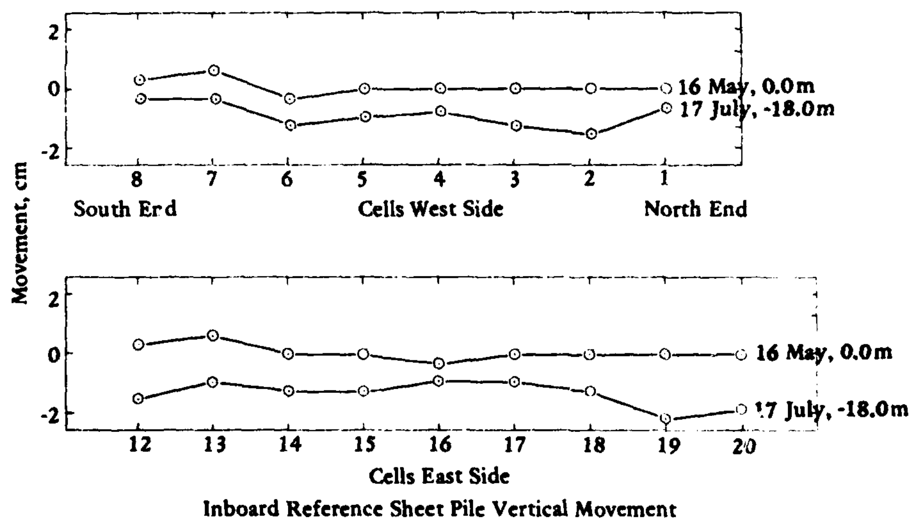


Figure 11. Vertical cell movements during dewatering of cofferdam.

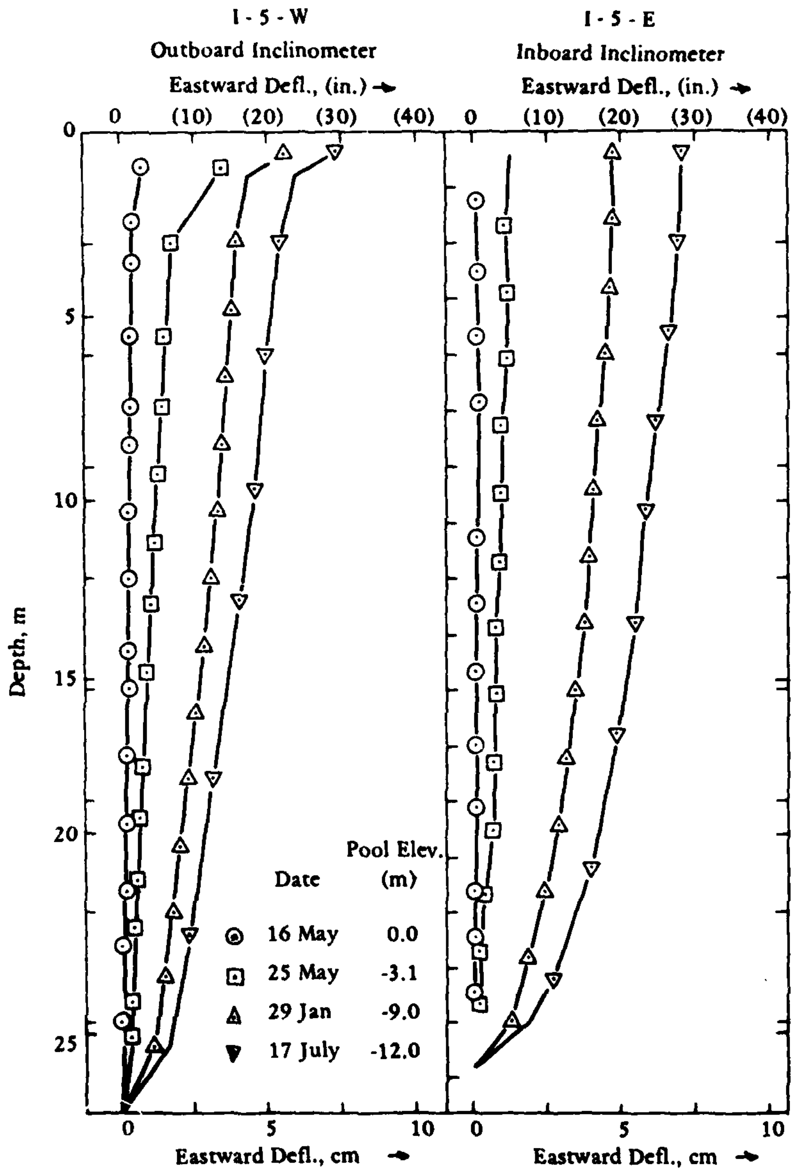


Figure 12. Inclinometer data for Cell 5.

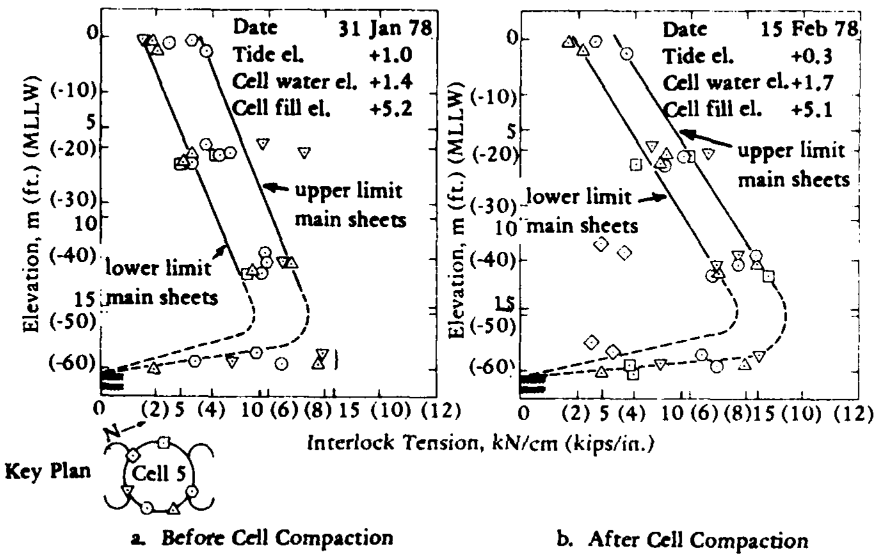


Figure 13. Interlock tension in Cell 5 before and after compaction.

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